The mass composition of ultra-high energy cosmic rays measured by new fluorescence detectors in Telescope Array experiment

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for the Telescope Array Collaboration

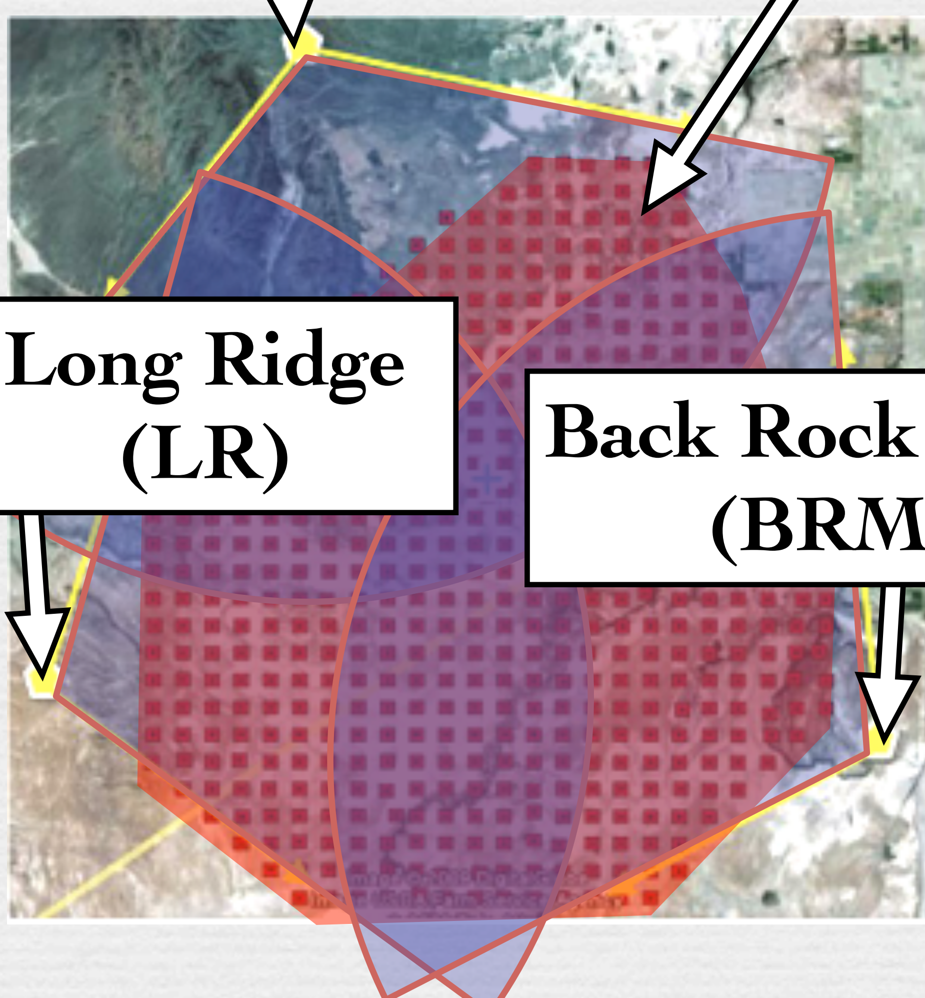
TAUP 2013

Telescope Array(TA) Experiment

- The largest detector in northern hemisphere : ~ 700 km^2
- Utah desert, US
- Hybrid detector using SDs and FDs
- Full operation in Mar 2008

Middle Drum (MD)

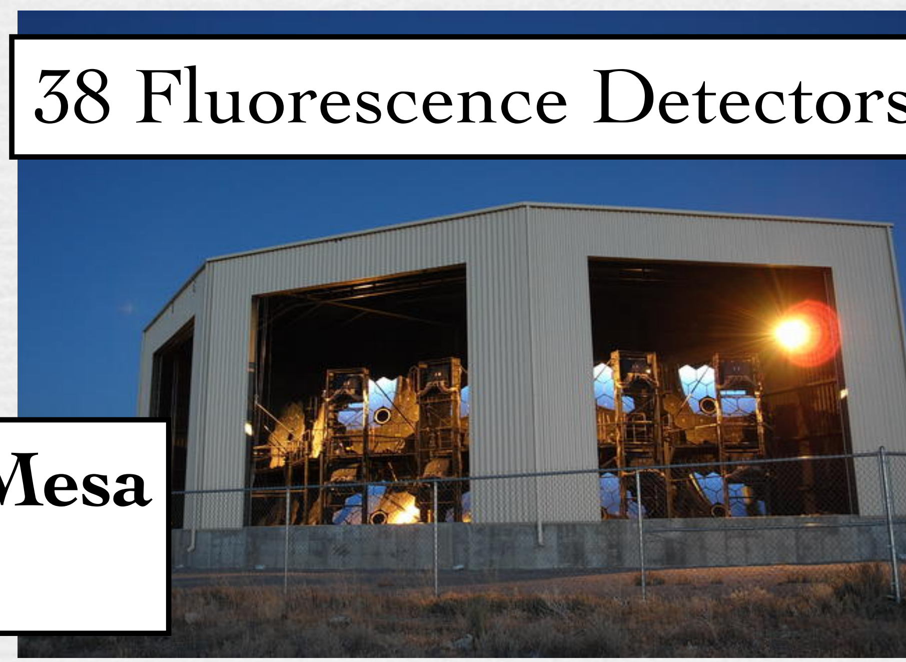
507 Surface Detectors

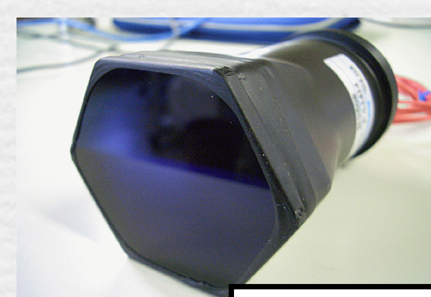


Long Ridge (LR)

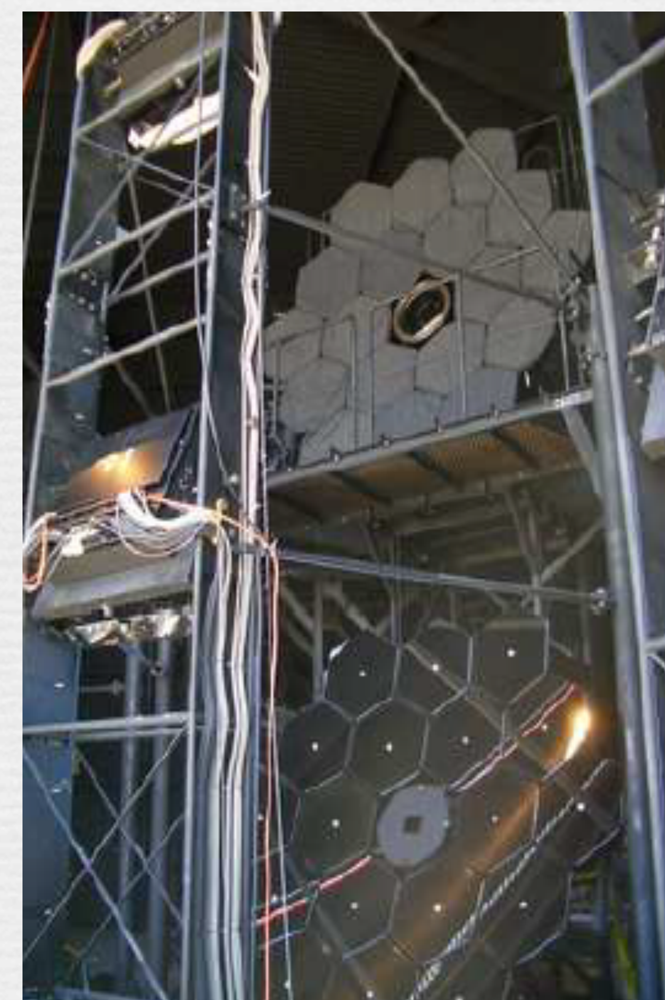
Back Rock Mesa (BRM)

38 Fluorescence Detectors



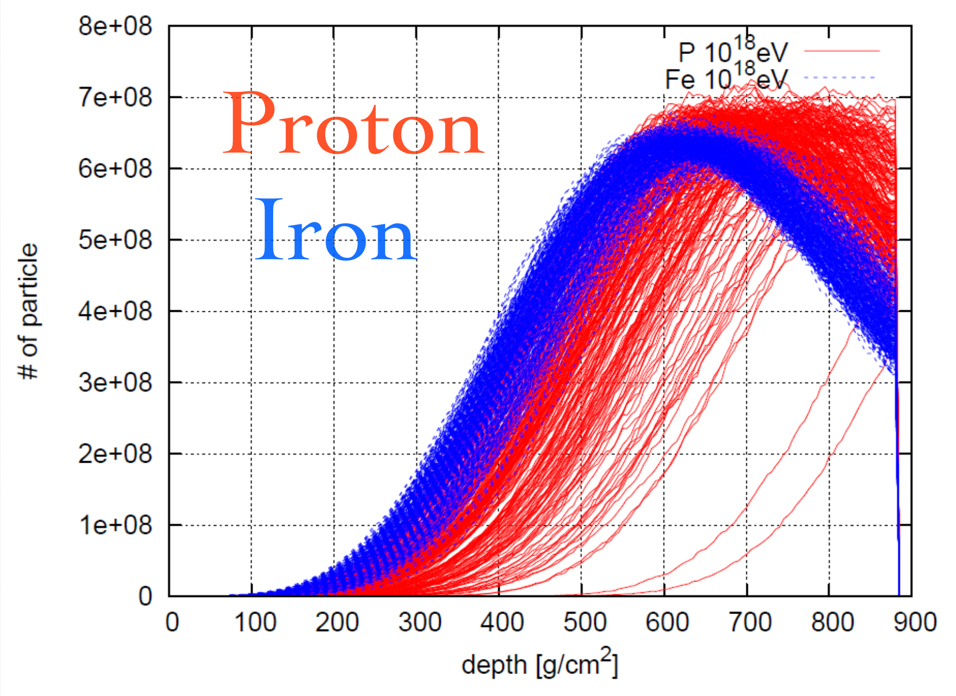


PMT



Mass Composition Measurements

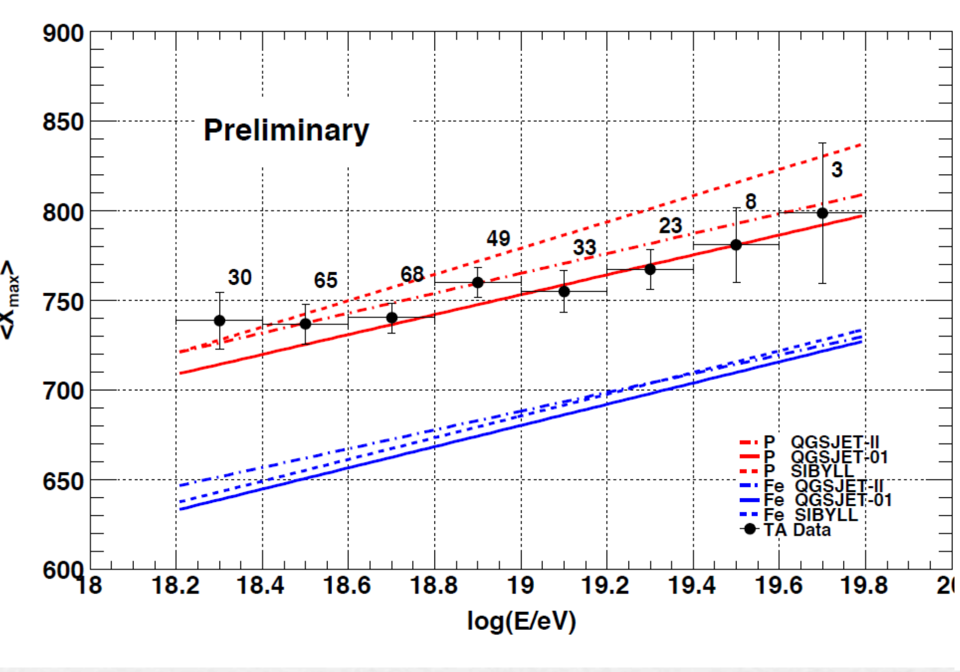
- Xmax depends on the mass composition of primary cosmic ray.
  - 100 g/cm^2 difference between proton and iron primaries.
  - A limited field of view for FDs leads to a bias on observed Xmax.



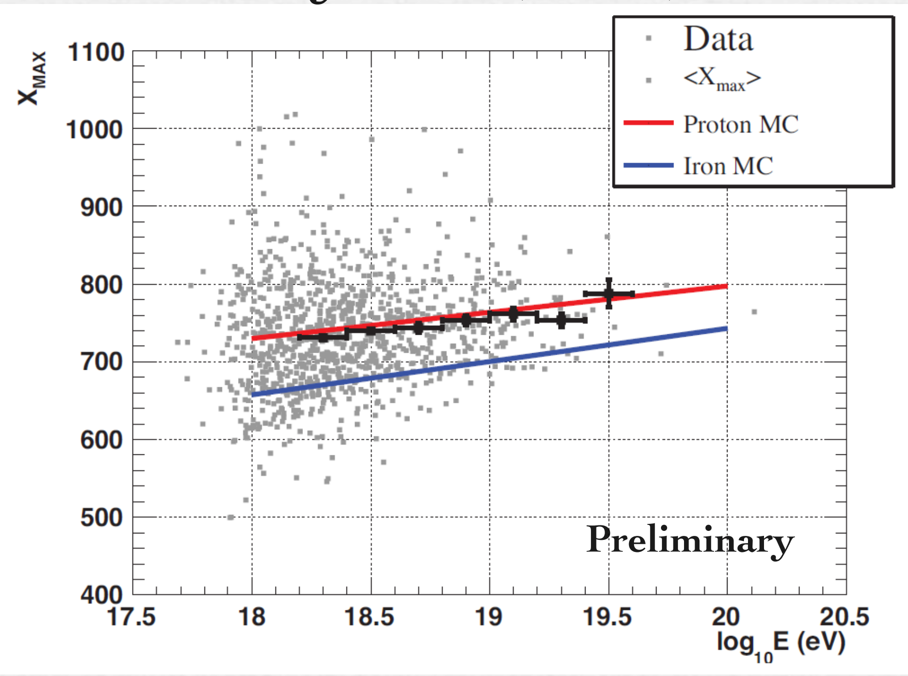
TA: Estimate the bias from MC simulations, and compare observed values.

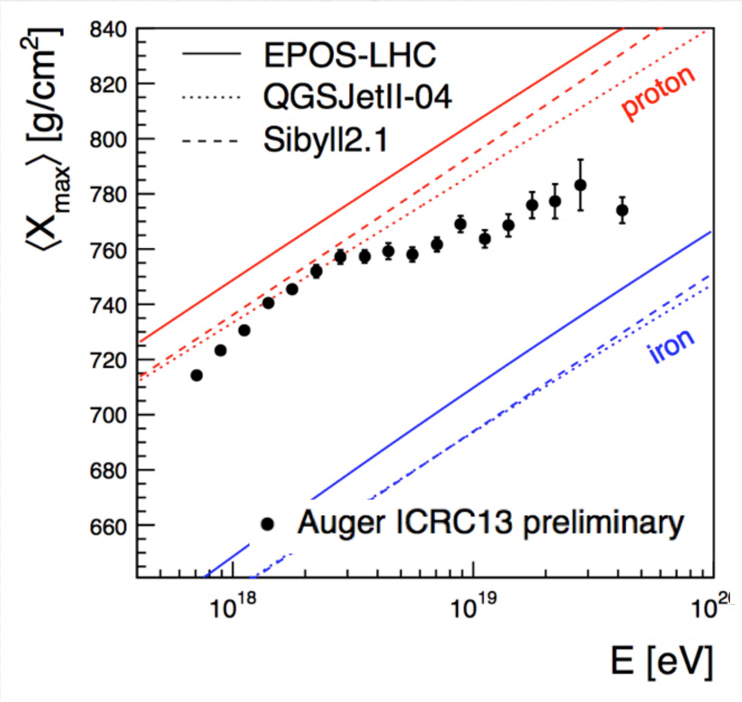
Auger: Bias free measurement by a fiducial volume cut.

Stereo(BRM+LR)



Hybrid(MD)





Overview of this work

- We analyze newly constructed FDs which are BRM and LR stations in monocular mode.
  - Larger statistics than Stereo or Hybrid analysis.
  - Broad energy range.
  - Poorer geometrical resolution.

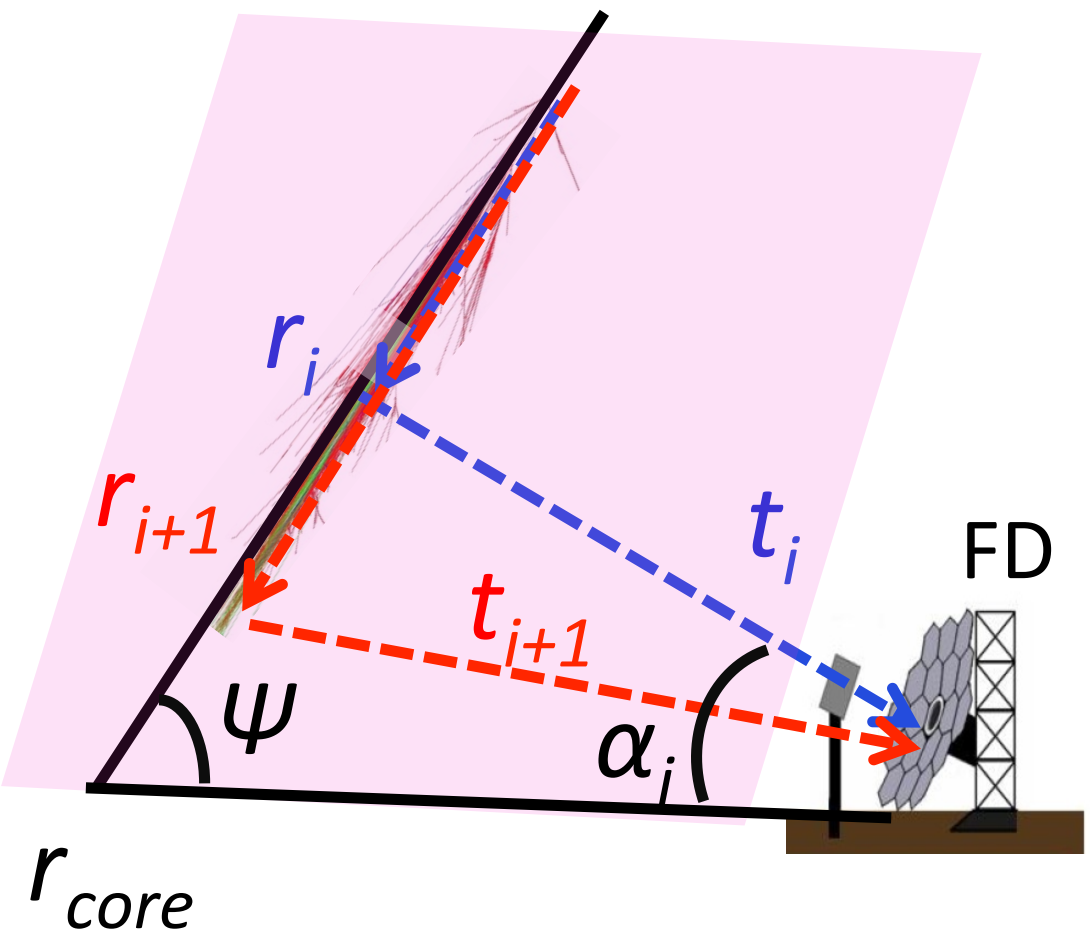
- To study the effect of fiducial volume cuts, we adopt tight cuts to avoid reconstruction bias and achieve reasonable resolutions on Xmax in monocular mode.

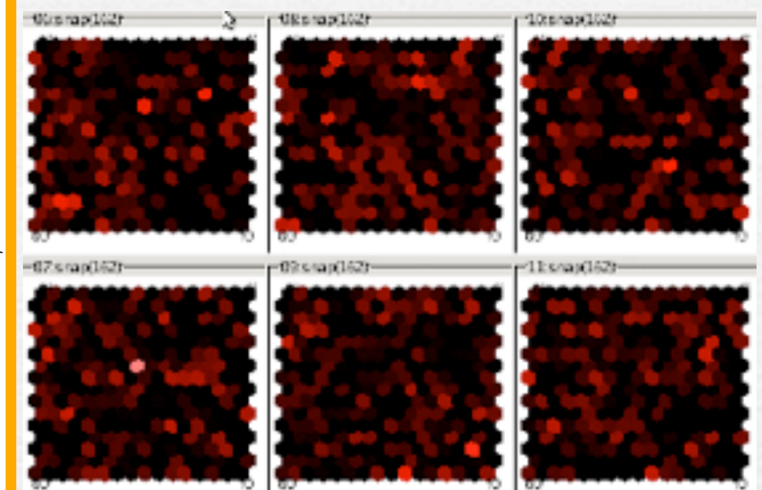
Geometry Reconstruction

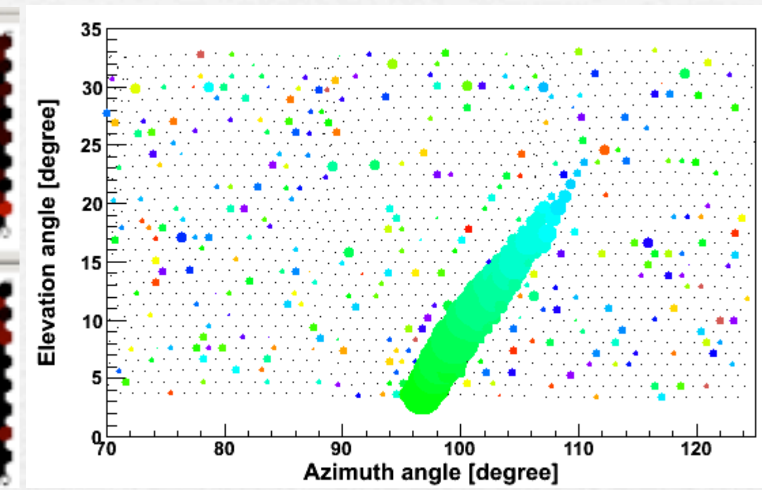
Monocular Mode

Timing fit in only 1 FD station

$$t_i = t_{core} + \frac{1}{c}\frac{\sin\psi - \sin\alpha_i}{\sin(\psi + \alpha_i)} r_{core}$$



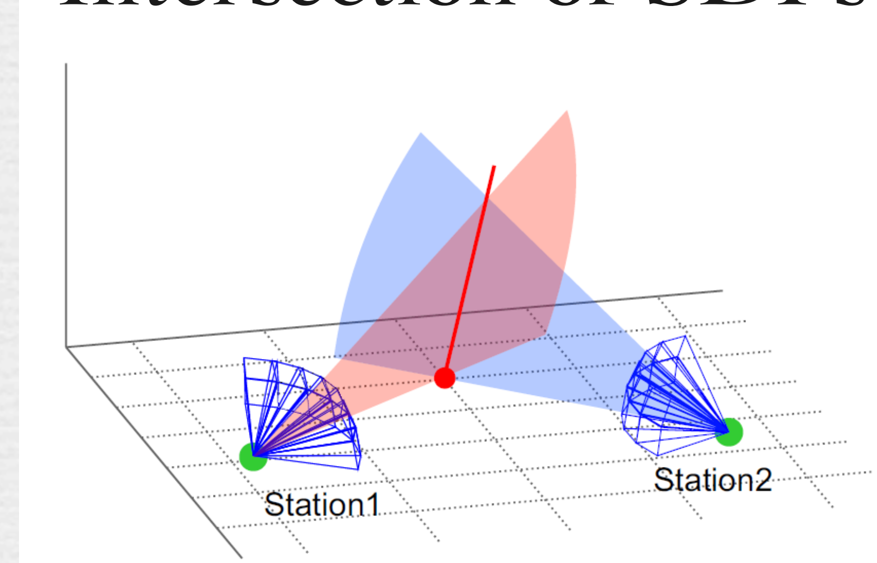




Stereo Mode

Triggered by 2 FD stations

Intersection of SDPs



SDP= shower detector plane

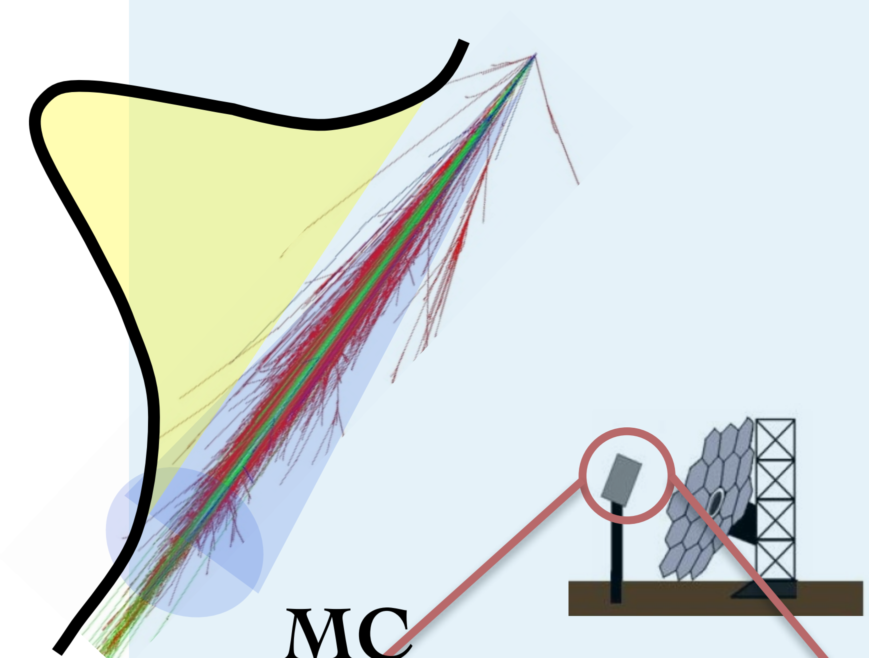
Profile Reconstruction

Reconstructed
Shower Geometry

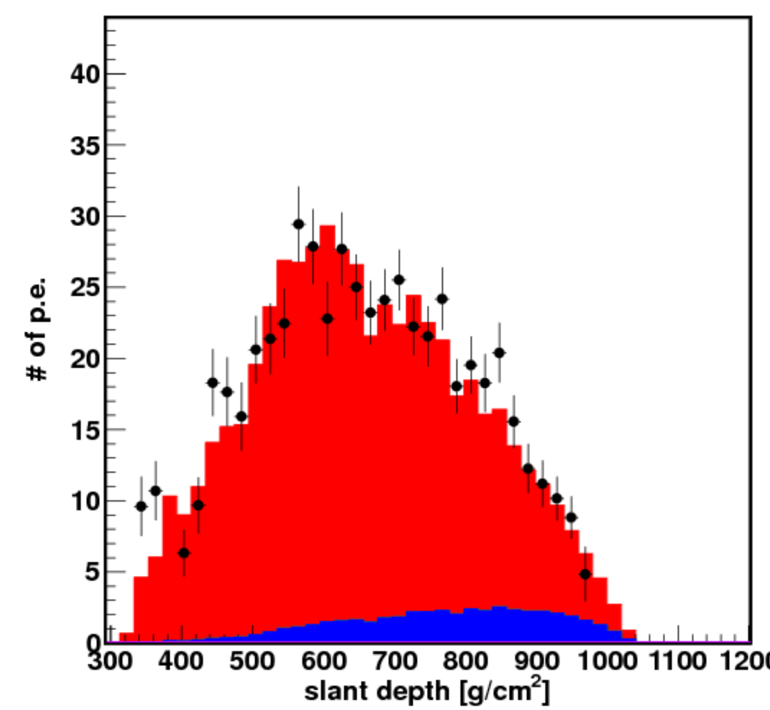
Inverse Monte Carlo

Repeatedly simulate shower images with changing longitudinal development parameters of Gaisser-Hilllas (G.H.) function.

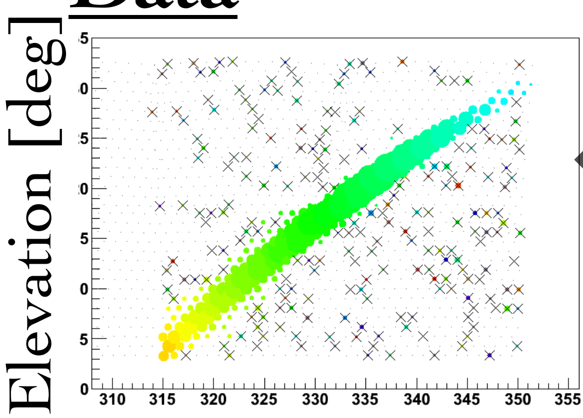
Shower
simulation based
on G.H.Function



Signal at camera

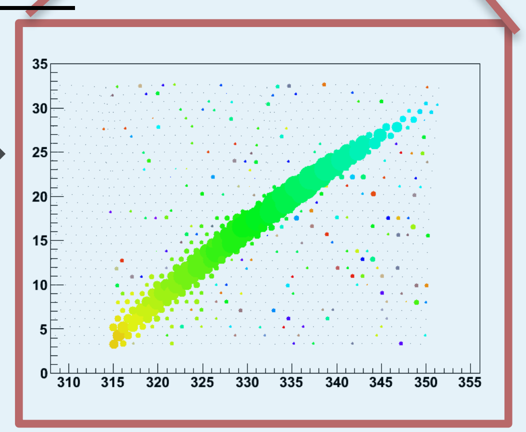


Data



Compare

MC



Size = brightness,   Timing Blue⇒Red

Plot: Data
Histogram(Red): Fluorescence (MC)
Histogram(Blue): Cherenkov (MC)

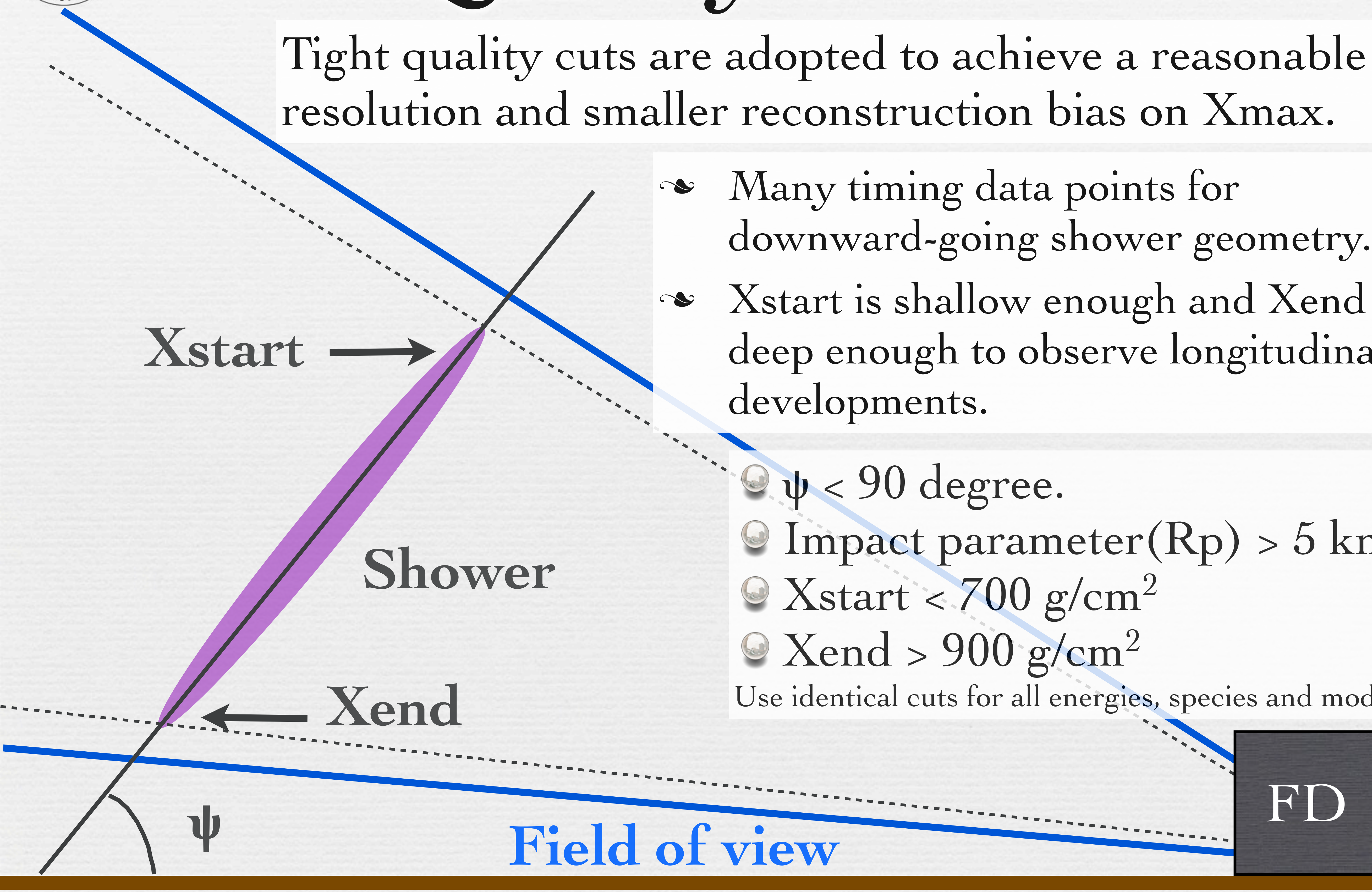
Quality Cuts

Tight quality cuts are adopted to achieve a reasonable resolution and smaller reconstruction bias on Xmax.

- Many timing data points for downward-going shower geometry.
- Xstart is shallow enough and Xend is deep enough to observe longitudinal developments.

- ψ < 90 degree.
- Impact parameter(Rp) > 5 km
- Xstart < 700 g/cm^2
- Xend > 900 g/cm^2

Use identical cuts for all energies, species and models.

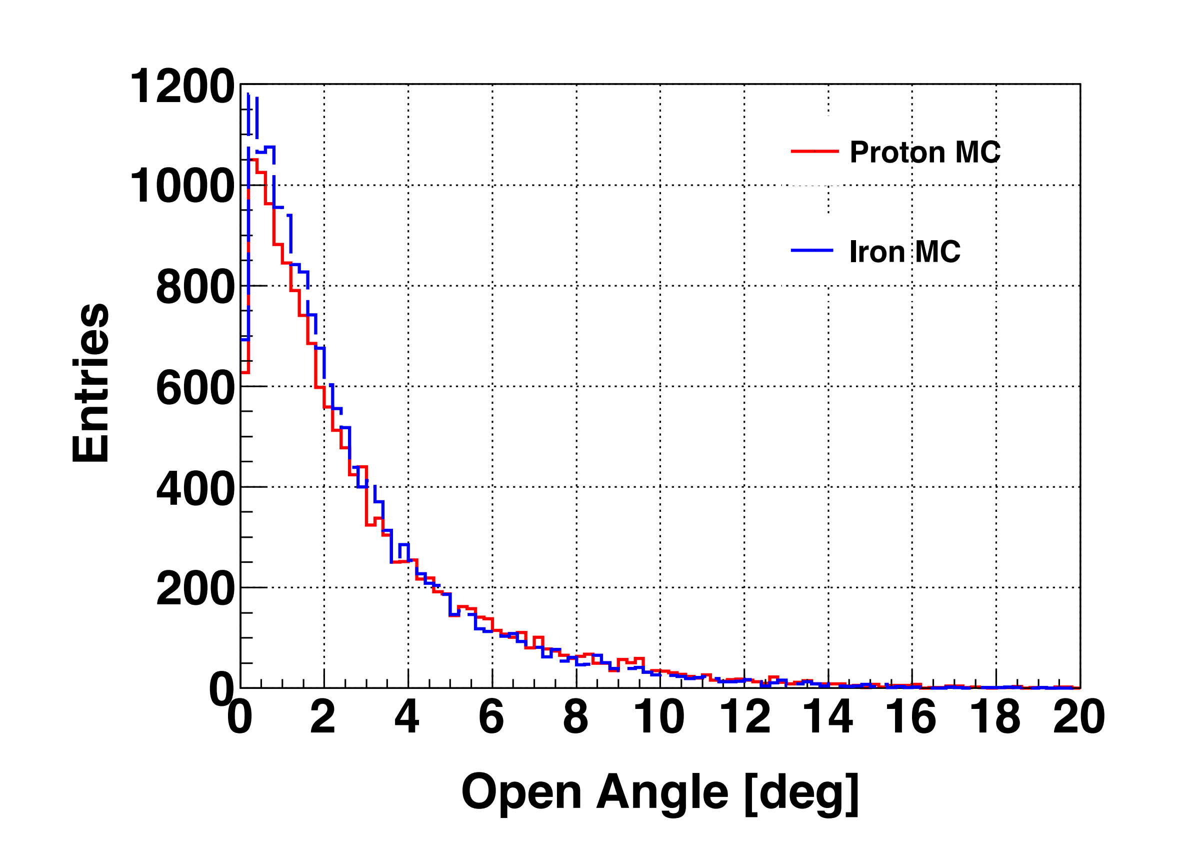


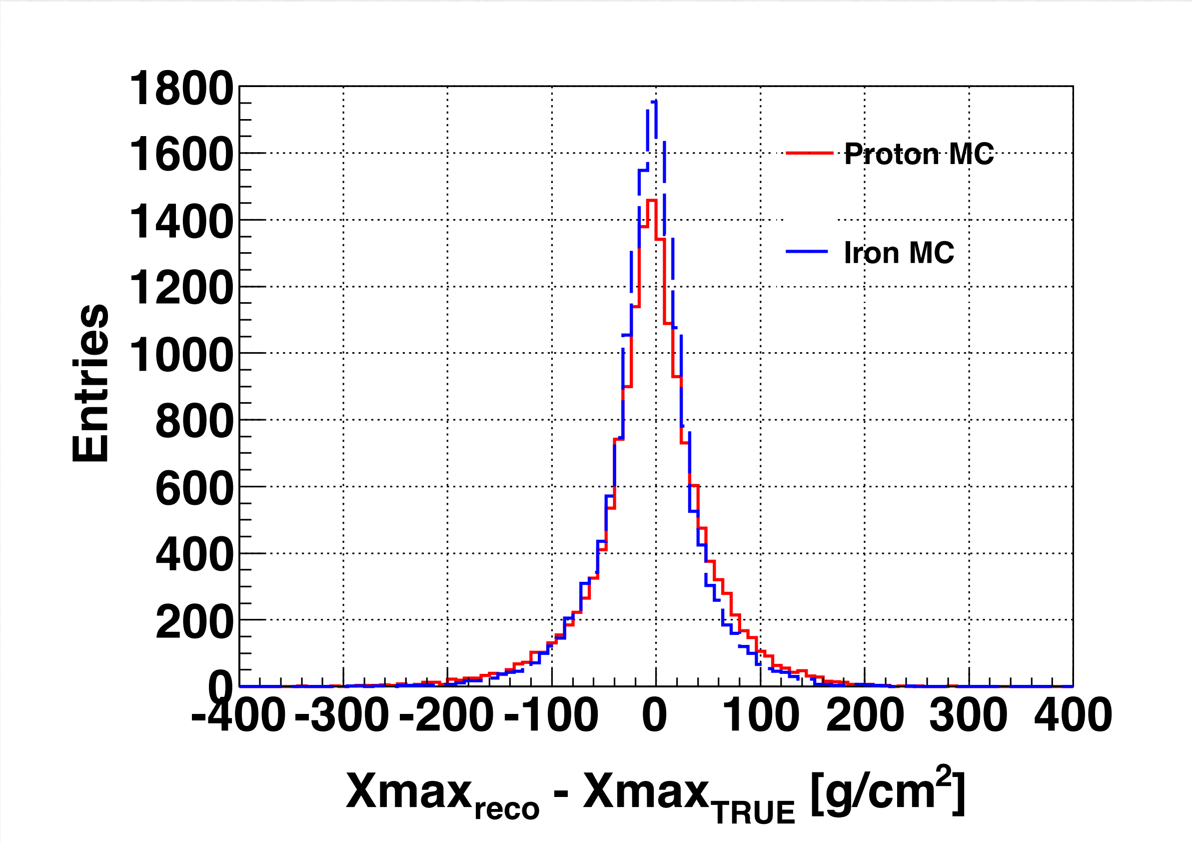
Resolution Study by MC

1. Generate artificial data calculated by MC simulations.
2. Reconstruct this simulated data in monocular analysis, and compare reconstructed results with true ones.

<u>Arrival Direction</u>
Proton: 3.0 deg. (68%)
Iron: 2.8 deg. (68%)

<u>Xmax</u>
Proton: 54.5 g/cm^2
Iron: 46.5 g/cm^2



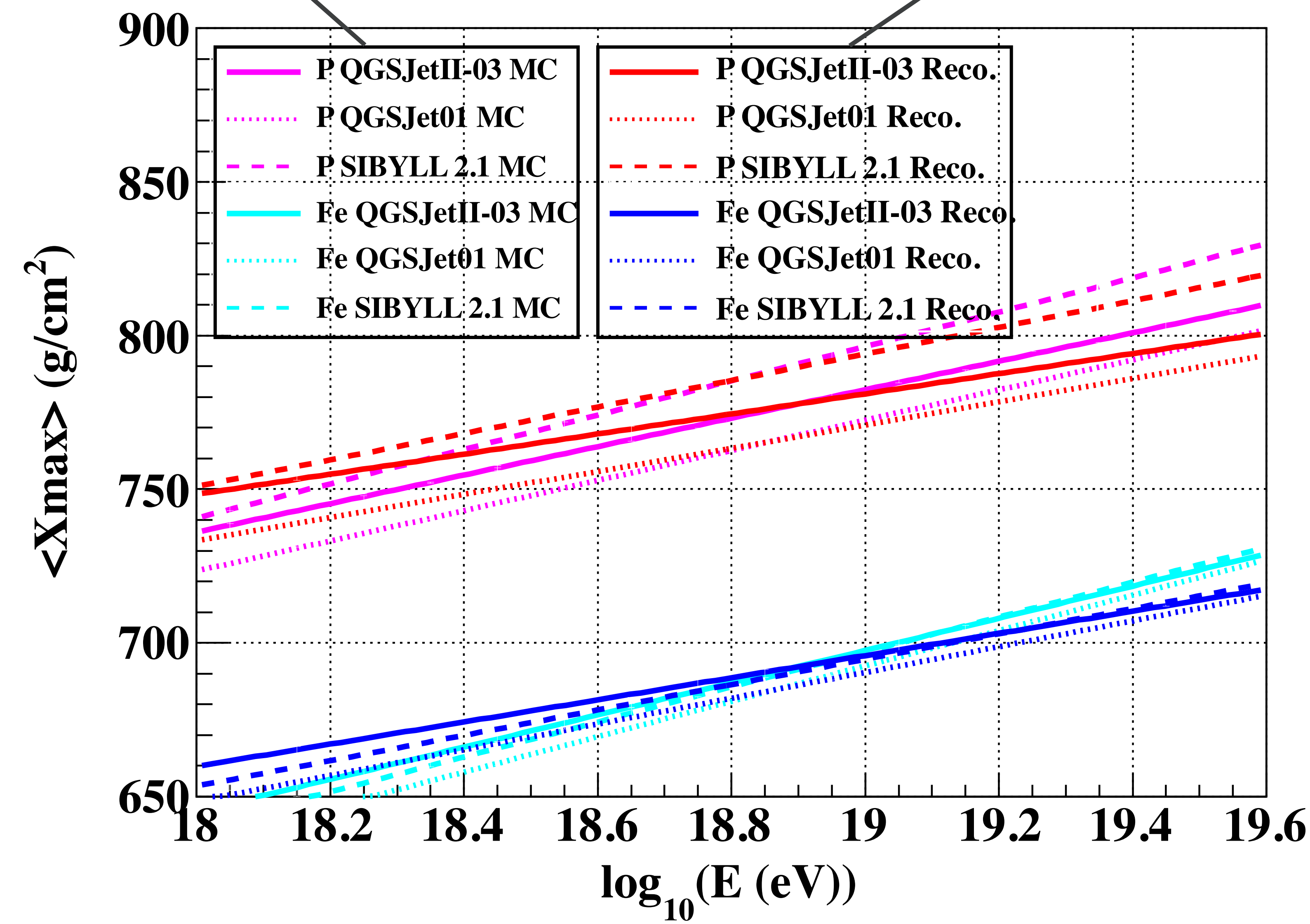


Reconstruction Bias on Xmax

Thrown Xmax
(CORSIKA Prediction)

Reconstructed Xmax
(With detector simulation)

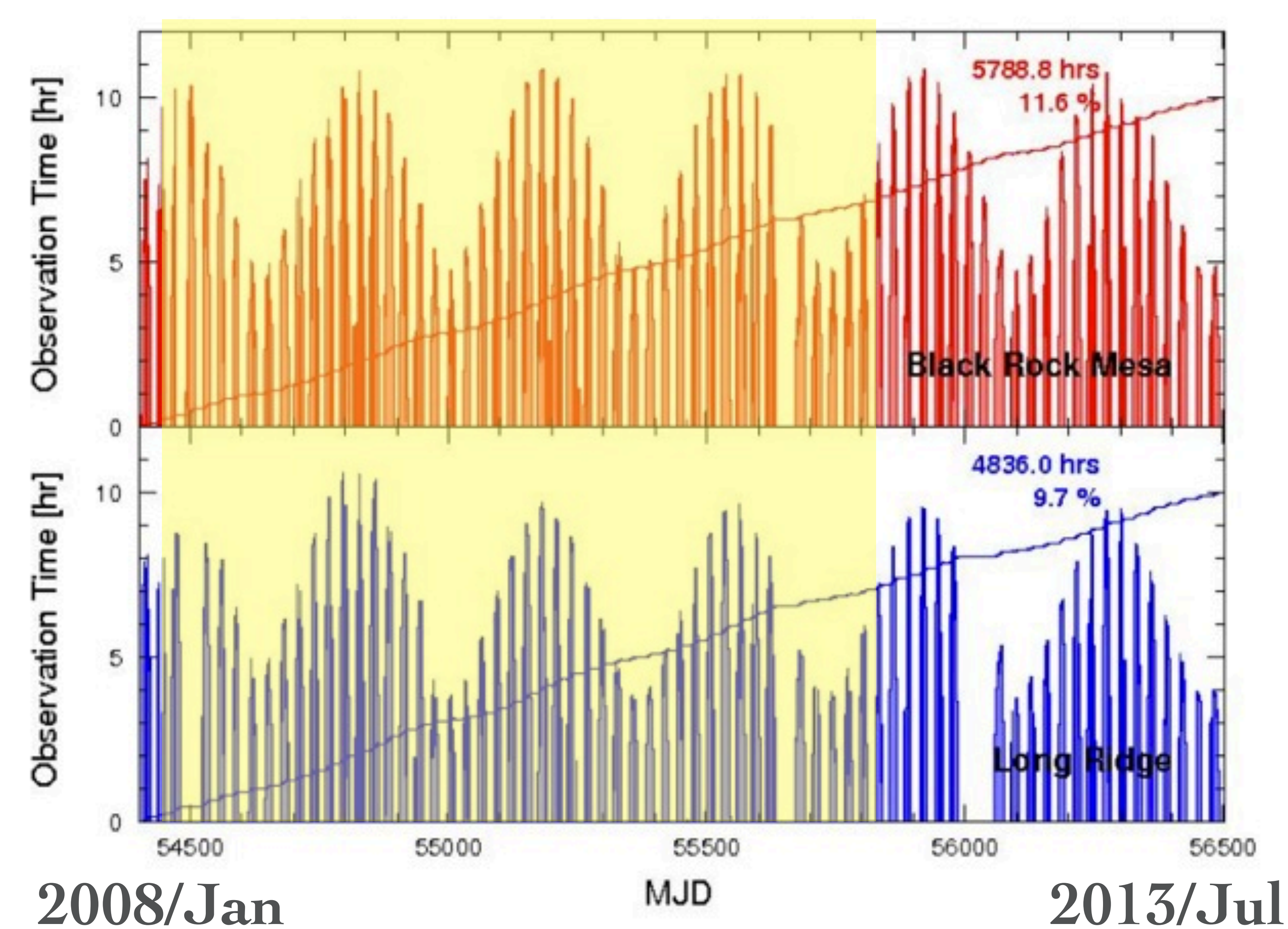
CORSIKA shower generation → Averaged Xmax



CORSIKA shower generation → Detector simulation → Reconstruction and quality cuts → Averaged Xmax

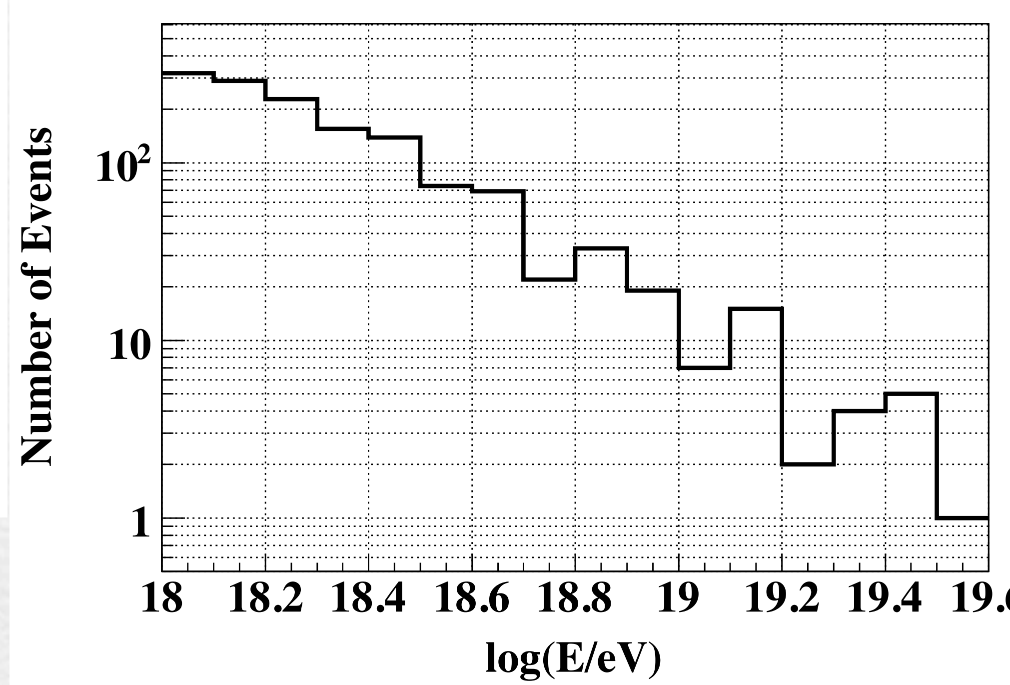
Reconstructed bias on Xmax is less than 10 g/cm^2 for all species and models.

Data Set and Analysis



Use identical reconstruction procedures and quality cuts in both observed and MC data.

Number of events



2008/Jan/01 ~ 2011/Sep/07 3.7 years

BRM: 2399 hrs (duty: 7.4%)

LR: 2054 hrs (duty: 6.3%)

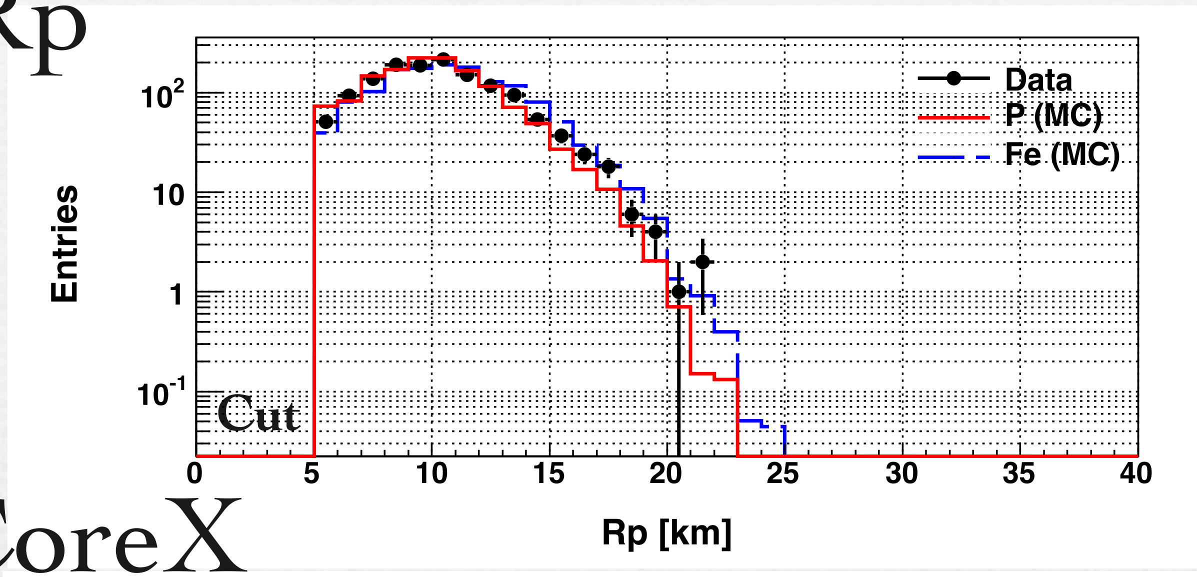
(cloud cut and dead time subtracted)

1381 showers

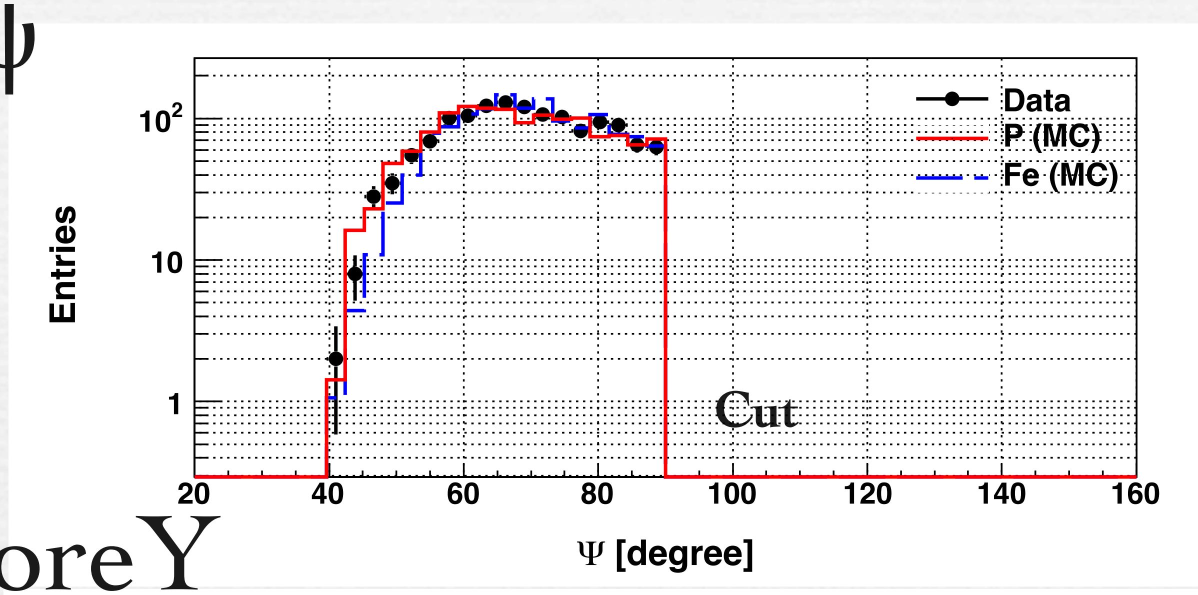
(logE>18.0, BRM&LR)

Data/MC Comparison

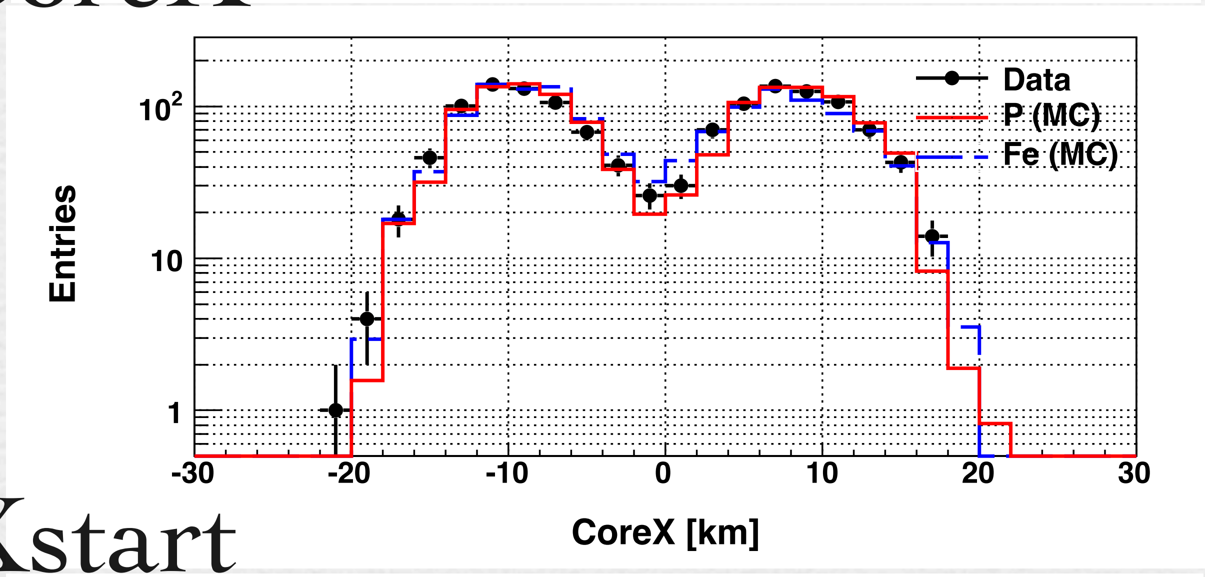
Rp



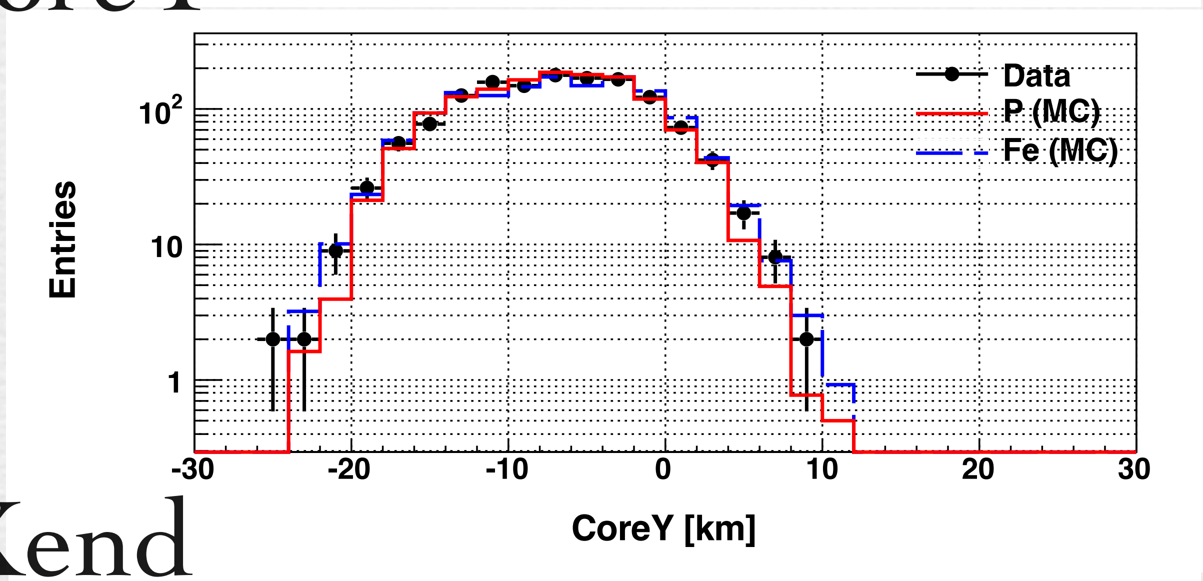
ψ



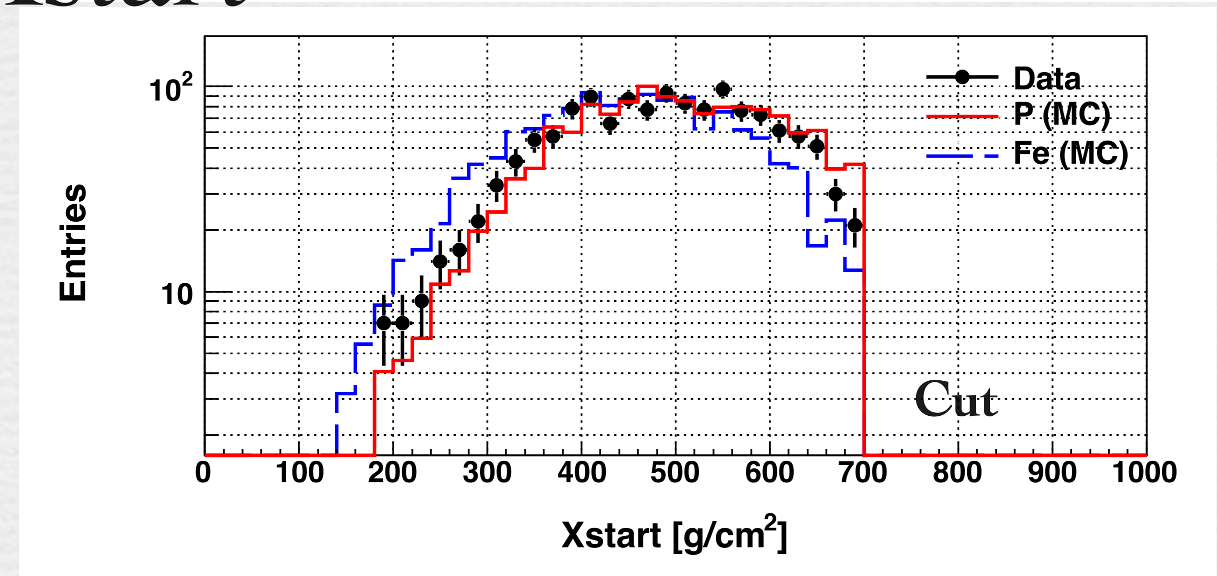
CoreX



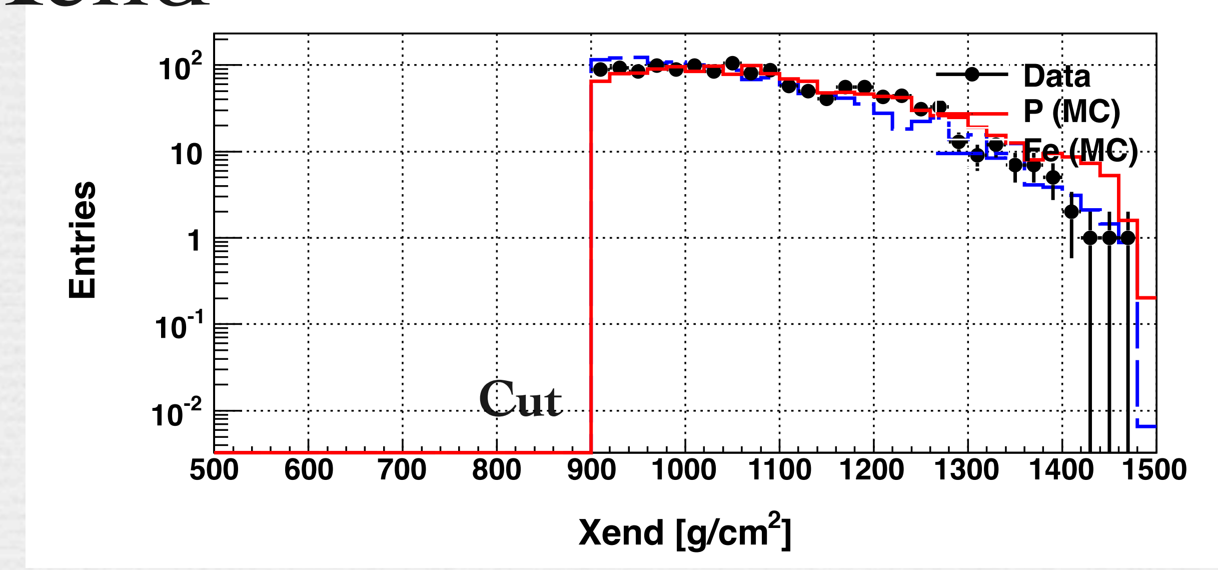
CoreY



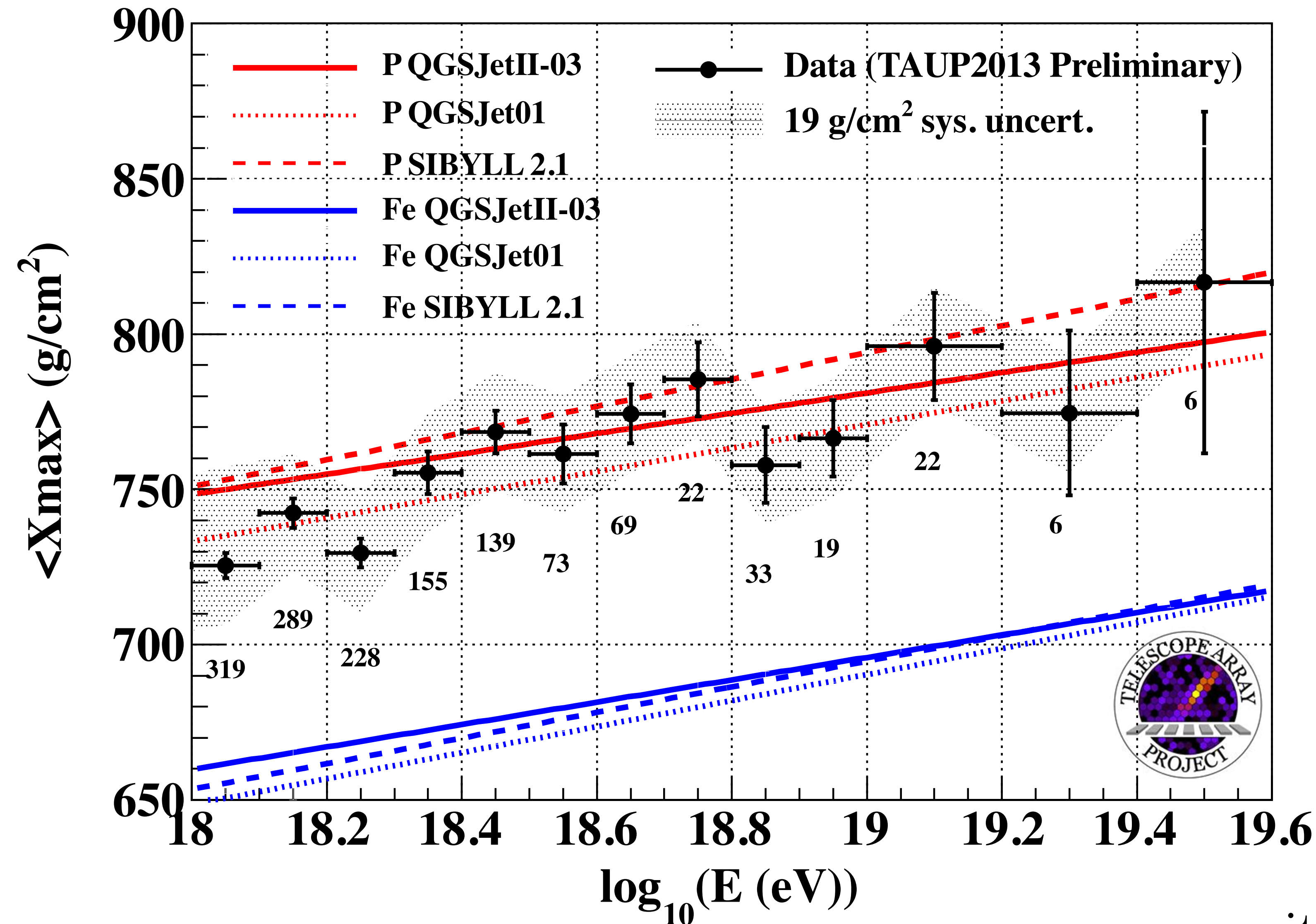
Xstart



Xend



Averaged Xmax

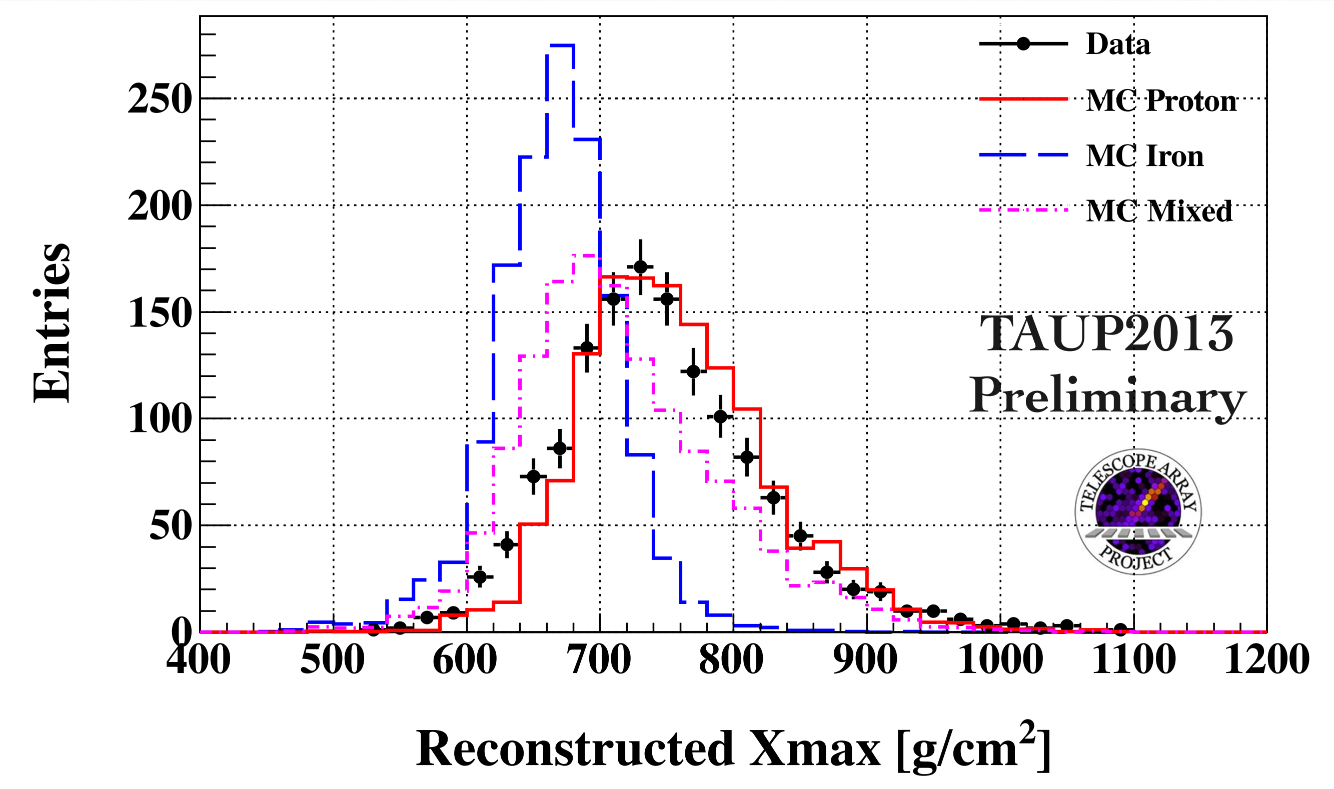


item	X_{max}
Fluorescence Yield	5 g/cm^2
Atmosphere	12 g/cm^2
Calibration	5 g/cm^2
Detector Geometry	9 g/cm^2
Reconstruction	10 g/cm^2
Total	**19 g/cm^2**

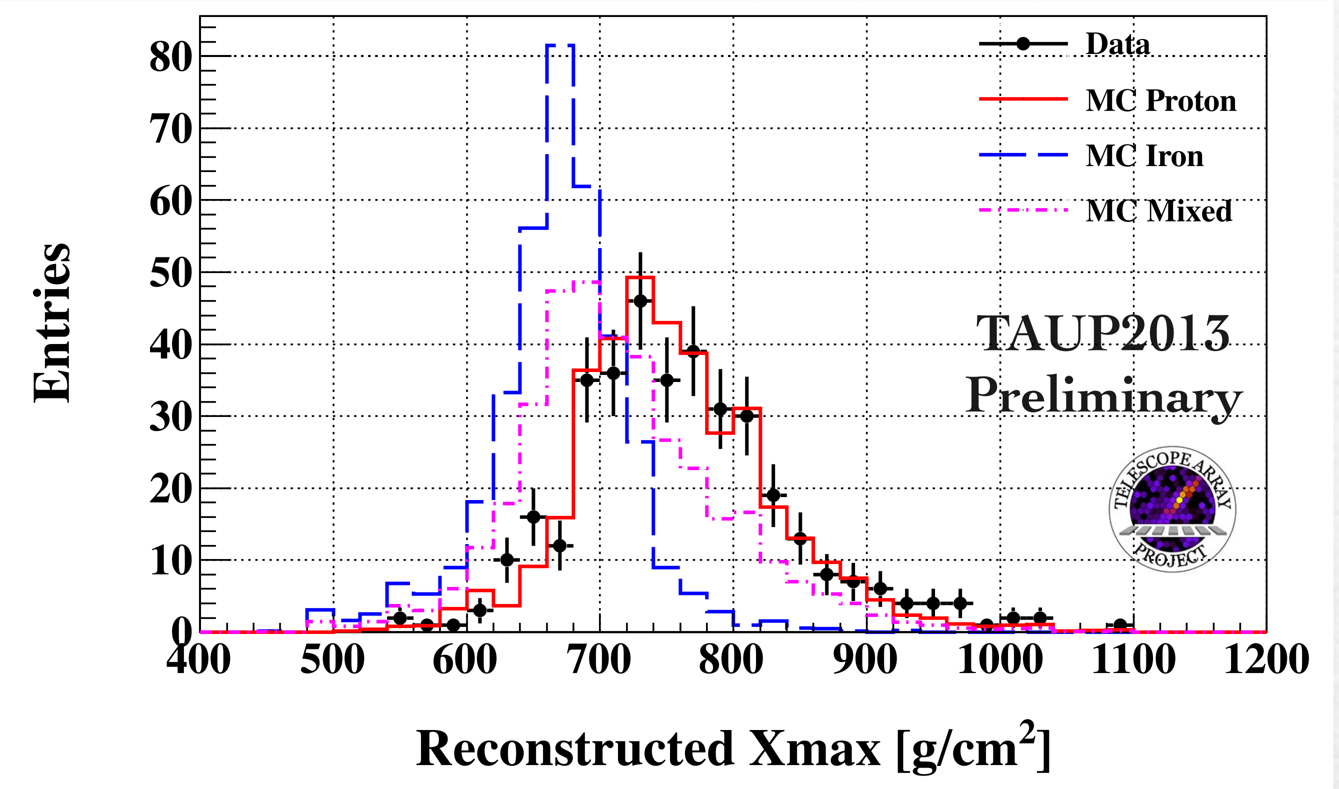
The measured Xmax is consistent with proton dominance.

Xmax distributions (QGSJetII-03)

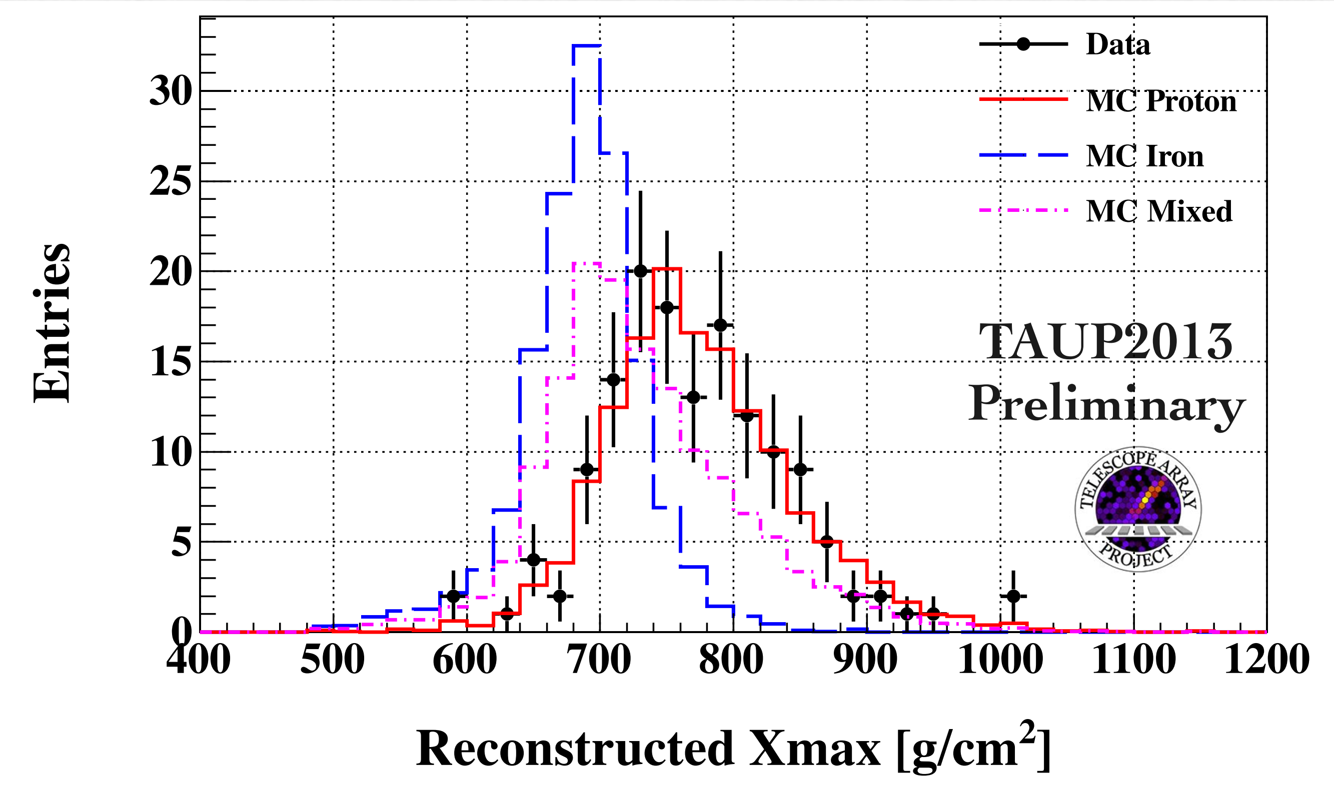
18.0≦logE<18.3



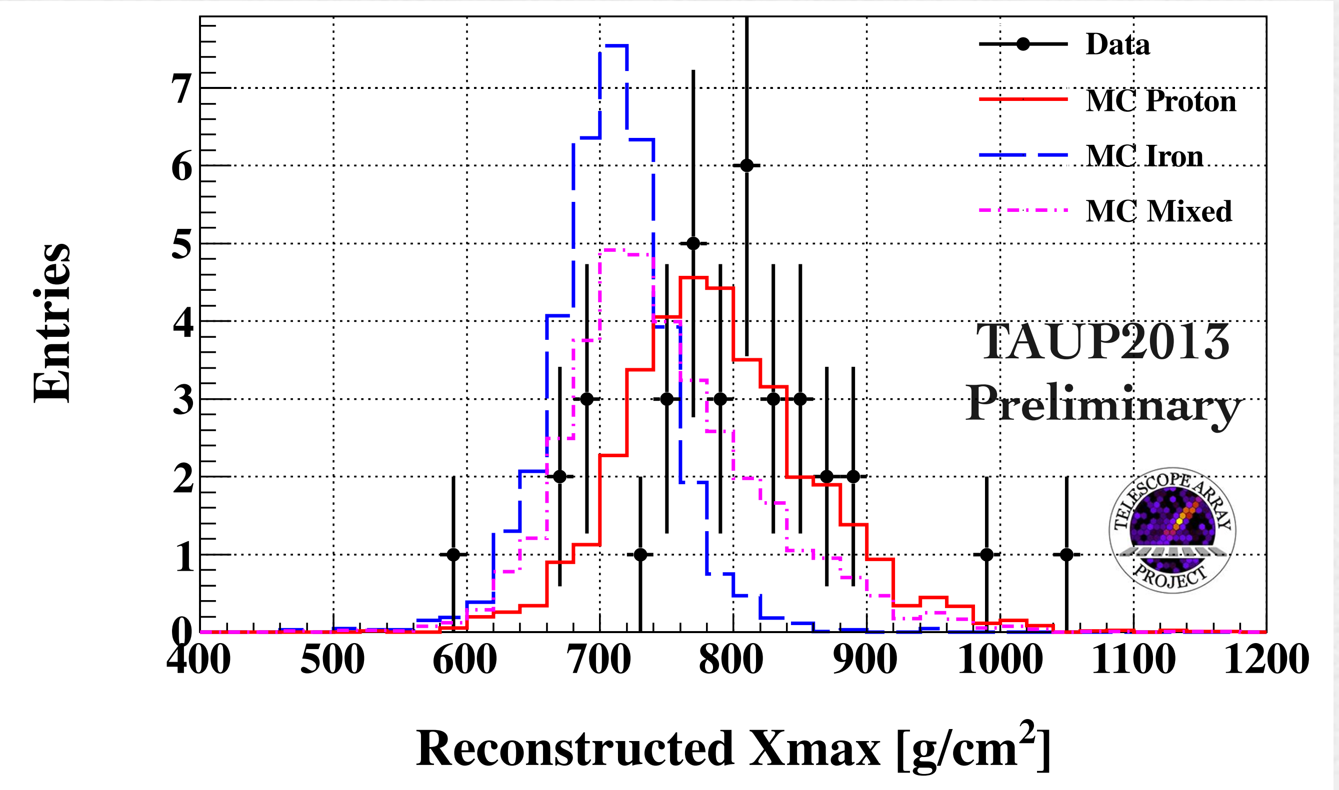
18.3≦logE<18.6



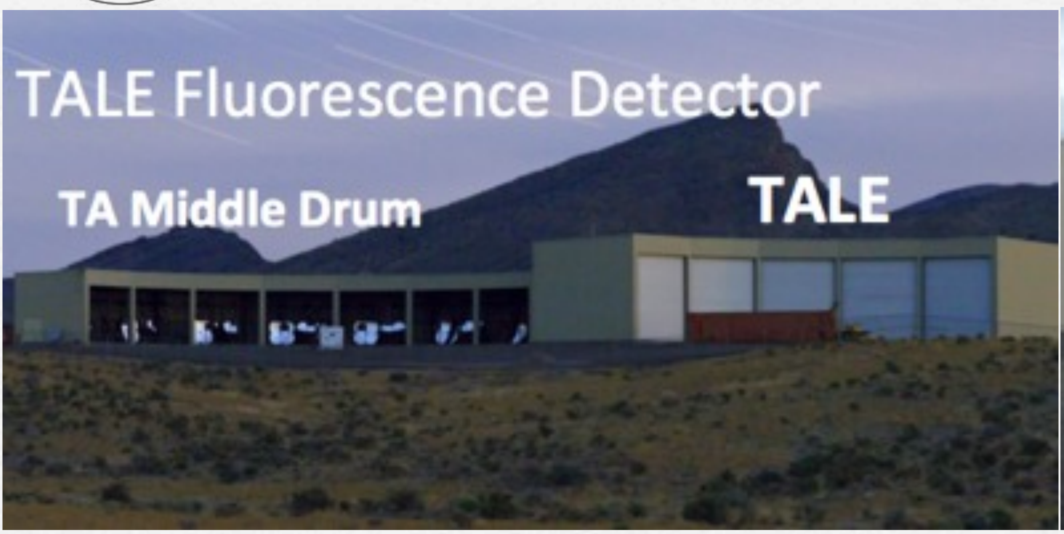
18.6≦logE<19.0

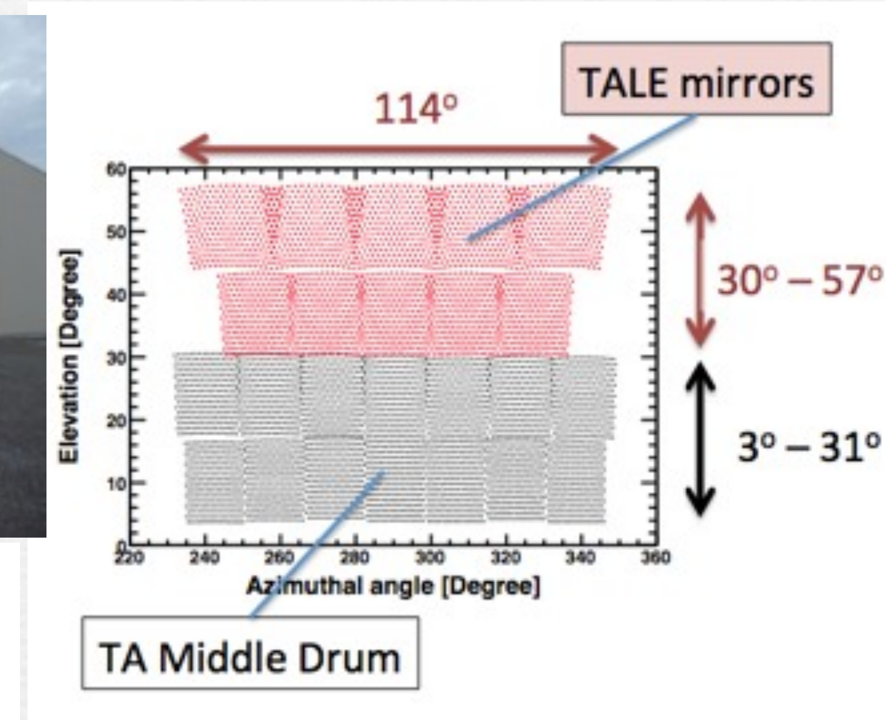


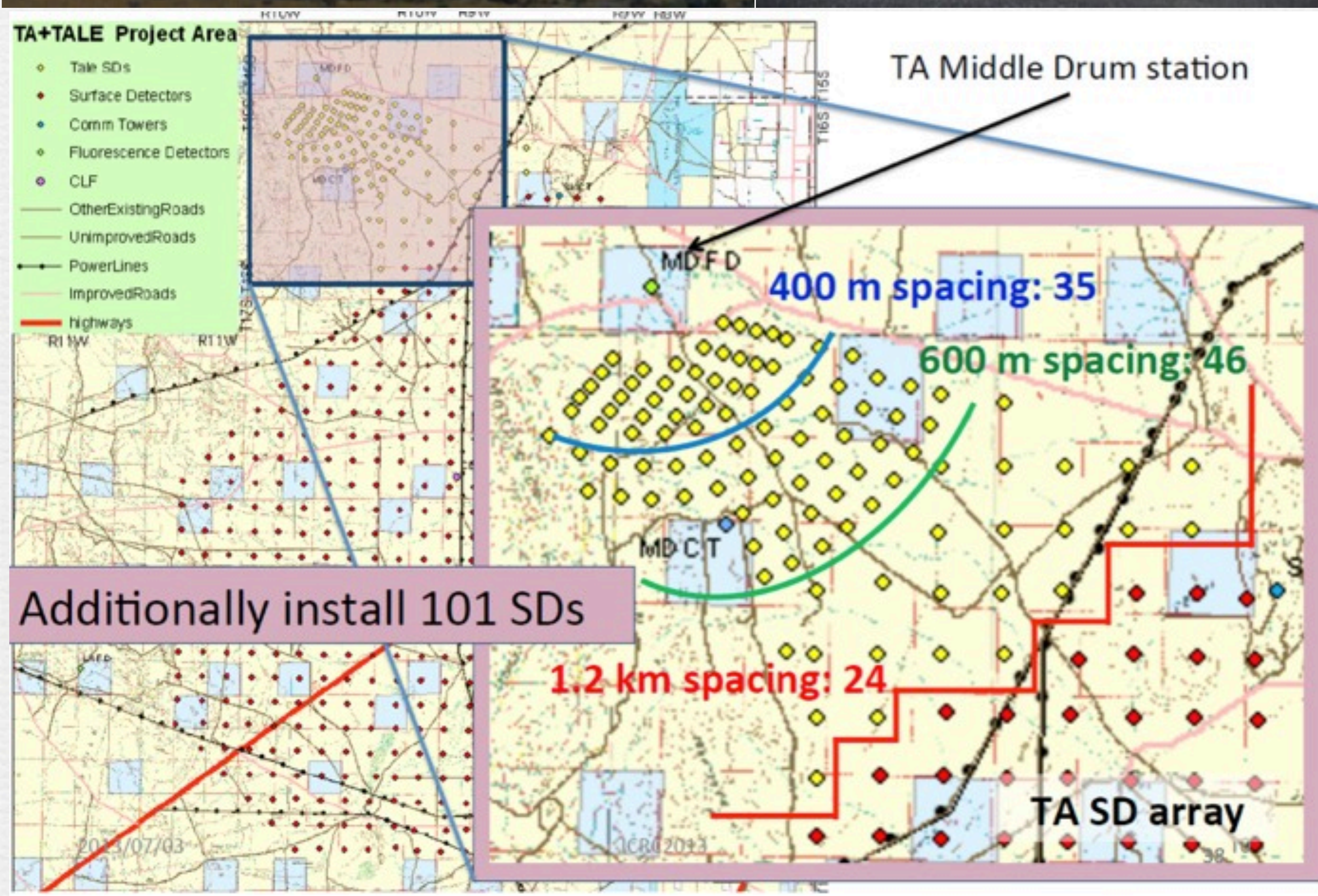
19.0≦logE

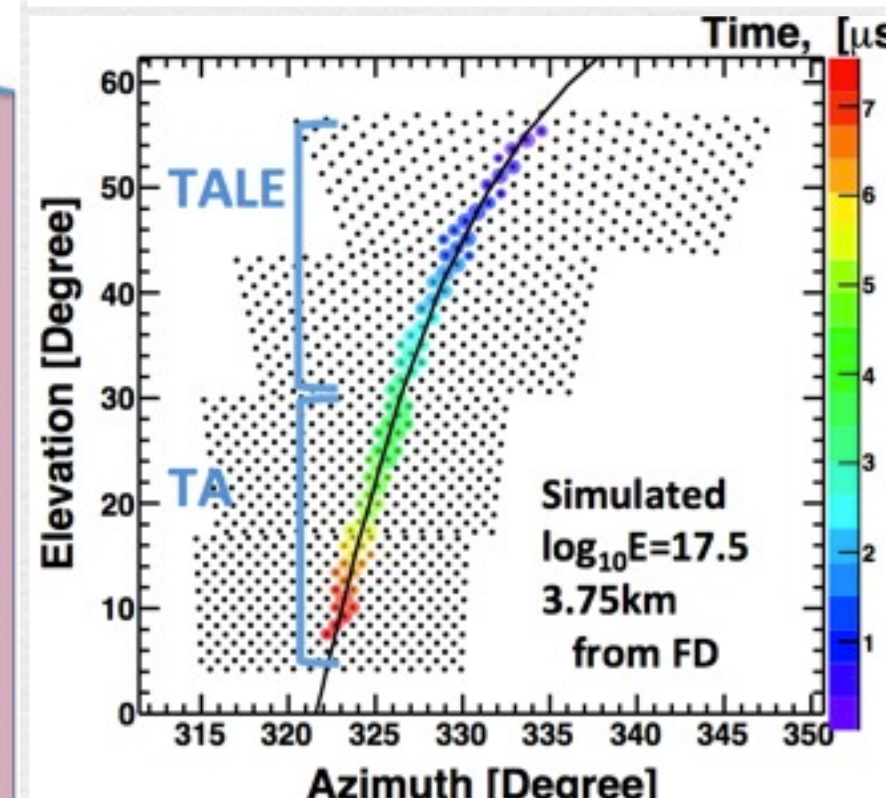


TALE(Telescope Array Low Energy Extension)









$E > 10^{16.5}$ eV

Summary and Future Plans

- We measured the mass composition to analyze data collected during 3.7 years by newly constructed fluorescence detector of TA in monocular mode.
    - Tight cuts are adopted to achieve reasonable resolution and smaller Xmax reconstruction bias.
- The measured Xmax is consistent with proton dominance, and also in good agreement with Stereo or Hybrid measurements.

- Use updated hadron interaction models, such as QGSJetII-04 and EPOS-LHC.
- Systematic uncertainty study for low energy showers